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(54) High tensile strength steel sheet excellent in processibility and process for manufacturing the same

(57) A high tensile strength steel sheet excellent in processibility which can satisfy a strength, a total elongation, and stretch-flanging property (hole enlarging rate) at a further high level. and comprises a matrix microstructure of tempered martensite or tempered bainite and, if necessary, ferrite, and a second phase of retained austenite, wherein (1) the steel comprising C: 0.10 to 0,6 mass%, Si: 1:0 mass% or smaller, Mn: 1.0 to 3 ,mass%, Al: 0.3 to 2.0 mass%, P: 0.02 mass% or smaller, S: 0.03 mass% or smaller, (2) a volume rate of retained austenite obtained by a saturated magnetization measuring method is 5 to 40% by area (whole field is 100%), and (3) a relationship of a carbon amount (C: weight%) in the steel, a volume rate ($f\gamma R$) of retained austenite and a carbon concentration ($C\gamma R$) of the retained austenite satisfies the equation:

$$(f\gamma R \times C\gamma R) / C \geq 50 \qquad (I)$$

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Description

BACKGROUND OF THE INVENTION

Field of the Invention

[0001] The present invention relates to a high tensile strength steel sheet excellent in processibility (stretch-flanging property and total elongation), and relates to technique for improving a TRIP (TRansformation Induced Plasticity) steel sheet.

Description of the Related Art

[0002] Steel sheets used for press molding in automobiles and industrial machines are required to have both of excellent strength and processibility, and such property requirements have been recently increased gradually. In order to respond to such demands, recently, TRIP steel sheets have been attractive and paid attention. TRIP steel sheets have a retained austenite, and the retained austenite (γR) is induced - transformed into martensite by a stress, and a great elongation is exhibited when processed and deformed at a temperature of a martensite transformation initiating temperature (Ms point) or higher. For example, TRIP - type composite steels (PF steel) comprising polygonal ferrite + bainite + retained austenite, and TRIP - type bainite steels (BF steel) comprising bainitic ferrite + retained austenite + martensite are known. However, the PF steel is inferior in stretch-flanging property, and the BF steel is excellent in stretch-flanging property, but has a defect that elongation is small.

[0003] Then, in order to provide a steel sheet which maintains excellent in balance between strength and elongation due to the retained austenite and also excellent in moldability such as stretch-flanging property (hole enlarging property), various studies have been performed. For example, the following Patent Publications 1 to 4 teach that steel sheets comprising a matrix microstructure of tempered martensite, tempered bainite and the like, and also a second phase microstructure of retained austenite, are excellent in all of strength, elongation and stretch-flanging property (U.S.Patent Application Publication No.: US-2004-0074575-A1). These steel sheets are manufactured by, for example, steps of adjusting a cooling rate after hot rolling to introduce a martensite and a bainite, performing cold rolling, and then cooling the plate from a ferrite - austenite two phase region temperature in a specific pattern to produce retained austenite.

SUMMARY OF THE INVENTION

[0004] Therefore, an object of the present invention is to provide a steel sheet which can satisfy balance between a strength, a total elongation and a stretch-flanging property (hole enlarging rate) at a considerably high level.

[0005] In order to achieve the aforementioned object, the present inventors intensively studied and, as a result, found the following facts:

1) If a steel material comprising a second phase (microstructure containing retained austenite) structure in which a content of Al in the steel material is relatively increased, and a carbon amount (C) in the steel, a volume rate ($f\gamma R$) of retained austenite occupied in the steel, and a carbon concentration ($C\gamma R$) in the retained austenite satisfy a predetermined relationship, the resulting steel can satisfy strength, a total elongation. a stretch-flanging property (hole enlarging rate) at a further high level.
2) In addition, it has been also found that , if a steel material can satisfy the above relationship of carbon amount (C), volume rate ($f\gamma R$) of retained austenite and carbon concentration ($C\gamma R$) in the retained austenite, a properly control rolling reduction rate at cold rolling prior to thermal treatment (2 phase region heating) for producing retained austenite, and also a retaining process in a predetermined temperature region for a predetermined time after cold rolling are effective to improve the strength, the total elongation and the stretch flanging property.

[0006] The present invention was made on the basis of these findings.

[0007] According to the first aspect of the present invention, there is provided a high tensile strength steel sheet excellent in processibility which comprises a matrix and a second phase, the matrix comprising at least tempered martensite or tempered bainite and, if necessary, ferrite as a constituent microstructure, and the second phase comprising retained austenite as a constituent, wherein

(1) the steel sheet comprises a steel satisfying C: 0.10 to 0.6 weight %, Si: 1.0 weight % or smaller, Mn: 1.0 to 3 weight %, Al: 0.3 to 2.0 weight %, P: 0.02 weight % or smaller, S: 0.03 weight % or smaller,
(2) a volume rate of retained austenite obtained by a saturated magnetization measuring method is 5 to 40% by

area (whole field is 100%), and

(3) a relationship of a carbon amount (C: weight%) in the steel, a volume rate ($f\gamma R$) of retained austenite and a carbon concentration ($C\gamma R$) of the retained austenite satisfies the following equation (I):

$$(f\gamma R \times C\gamma R) / C \geq 50 \qquad \text{(I)}$$

[0008] The high tensile strength steel sheet may further contain (a) an element for controlling the form of sulfide such as Ca: 0.003% by mass or smaller, and REM: 0.003% by mass or smaller, (b) an element for strengthening precipitation and finely dividing a microstructure such as Nb: 0.1% by mass or smaller, Ti: 0.1% by mass or smaller, and V: 0.1% by mass or smaller, and (c) an element for stabilizing retained austenite such as Mo: 2% by mass or smaller, Ni: 1% by mass or smaller, Cu: 1% by mass or smaller, and Cr: 2% by mass or smaller.

[0009] Preferable area rates (an area of a whole photograph is 100%) of tempered martensite, tempered bainite and ferrite are, when measured with an optical microscope photograph, as follows:

Tempered martensite or tempered bainite: 20 to 90% by area
Ferrite: 0 to 60% by area

[0010] It is desirable that the retained austenite contains lath-like retained austenite having a long axis/short axis ratio of 3 or larger at 60% by area relative to total retained austenite.

[0011] In the high tensile strength steel sheet of the present invention, even when a tensile strength (TS) is 750 to 1050MPa, a tensile strength (TS), a total elongation (E1) and a hole enlarging rate (λ) satisfy a relationship of the following equation:

$$TS \times E1 \geq 22{,}000,\ TS \times \lambda \geq 20{,}000$$

[wherein TS represents result of measurement of a tensile strength (unit: MPa), E1 represents result of measurement of a total elongation (unit: %), and λ represents result of measurement of a hole enlarging rate (unit: %)]

[0012] The high tensile strength steel sheet of the present invention includes a steel sheet in a naked state, as well as a steel sheet having a surface which has been rust proofing-processed by galvanizing, more specifically melting-galvanizing, further specifically melting-alloy-galvanizing in order to suppress rusting during storage or conveyance or during use to suppress quality deterioration.

[0013] According to the second aspect of the patent invention, there is provided a method of preparing a high tensile strength steel sheet which comprises steps of providing a steel sheet comprising C: 0:10 to 0.6% by mass, Si: 1.0% by mass or smaller (including 0% by mass), Mn: 1.0 to 3% by mass, Al: 0.3 to 2.0% by mass, P: 0.02% by mass or smaller, and S: 0.03% by mass or smaller, with a martensite or bainite introduced therein and cold rolling a steel sheet at rolling reduction rate of 30% or smaller, thereafter, or without performing cold rolling, heating the steel sheet to a ferrite-austenite 2-phase region temperature, and then retaining the steel sheet in a temperature range of 450 to 550°C for 10 to 500 seconds.

[0014] In addition, when a galvanized, more specifically, melting-alloy-galvanized steel sheet is manufactured by the present invention process, it is possible not only to perform plating treatment or alloy heating treatment after the 2-phase region temperature region heating step and/or retaining step in a temperature range of 450 to 550°C and, thereafter, but also to perform melting-galvanizing, further, alloy heating treatment of the plated layer from the 2-phase region temperature region heating or retaining step in a temperature region of 450 to 550°C, whereby, a galvanized steel sheet, or further an alloy heat-treated steel sheet thereof can be effectively obtained.

[0015] The present invention includes in its technical scope the aforementioned high tensile strength steel sheet and a galvanized article thereof and, further, various steel parts obtained by processing an alloy heat-treated steel sheet thereof.

[0016] According to the present invention, there can be provided a second phase (microstructure including retained austenite) steel sheet and a galvanized steel sheet which can satisfy a strength, a total elongation, and stretch-flanging property (hole enlarging rate) at a further high level.

BRIEF DESCRIPTION OF THE DRAWINGS

[0017] The above and other objectives and features of the present invention will become more apparent from the following description of preferred embodiments thereof with reference to the accompanying drawings throughout which like parts are designated by like reference numerals, and wherein:

Fig. 1 is a view showing one example of a hot rolling and cooling step adopted in Examples;
Fig. 2 is a view showing another hot rolling and cooling step adopted in Examples;
Fig. 3 is a graph showing influence of an austemper temperature after soaking on a value of the equation (I);
Fig. 4 is a graph showing influence of an austemper time after soaking on a value of the equation (I);
Fig. 5 is a graph showing influence of an austemper temperature after soaking on an amount of retained austenite in the resulting steel sheet; and
Fig. 6 is a graph showing influence of an austemper time after soaking on an amount of retained austenite in the resulting steel sheet.
Fig. 7 is a graph showing a change of temperature in a continuous annealing process and a continuous galvanizing process.
Fig. 8 is a graph showing changes of the tensile strength (TS), the total elongation (EL) and the hole enlarging rate (λ).depending on the alloy heat treatment temperature (T °C).
Fig. 9 is a graph showing changes of the tensile strength (TS), the total elongation (EL) and the hole enlarging rate (λ).depending on the alloy heat treatment time at 550 °C.
Fig.10 is a graph showing the retained γ property of the microstructure depending on the alloy heat treatment temperature (T °C).

BEST MODE FOR CARRYING OUT THE INVENTION

[Microstructure]

[0018] The steel sheet of the present invention is characterized by a microstructure and a component. First, the microstructure characterizing the present invention will be explained.

[0019] A metal microstructure of the steel sheet of the present invention observed with an optical microscope has a matrix microstructure and a second-phase which is dispersed in the matrix in an island manner. According to an optical microscope photograph, the matrix exhibits gray color, and is constructed of at least a tempered martensite or a tempered bainite. The matrix may contain a ferrite in addition to the tempered martensite or the tempered bainite, in some cases. On the other hand, the second phase (island-like phase) exhibits white color in an optical microscope photograph, and is constructed of retained austenite. In addition, a black part constructed of cementite is observed in some times, and the black part is contained in the second-phase microstructure in that the part is dispersed in an island manner.

[0020] It is an important point that the steel sheet of the present invention has the aforementioned microstructure, in order to balance a strength, a total elongation, and stretch-flanging property (hole enlarging rate) at a high level. That is, the tempered martensite and the tempered bainite are characterized in that crystal particles are lath-like and high in a hardness, but have a smaller translocation density and are soft as compared with the conventional martensite and bainite. These "tempered martensite and tempered bainite" and "martensite and bainite" can be discriminated by observation, for example, with a transmission electron microscope "TEM". Existence of "tempered martensite" and "tempered bainite" as a matrix becomes an important factor for enhancing both of a total elongation and stretch-flanging property.

[0021] The aforementioned matrix may contain ferrite in addition to the aforementioned tempered martensite and tempered bainite. This ferrite is correctly polygonal ferrite, that is, ferrite having a small translocation density. When ferrite is contained, the stretch flanging property can be further enhanced. For example, when an area rate of a phase is measured with an optical microscope photograph, a TEM photograph or hardness measurement (microstructures can be discriminated by a TEM observation or hardness measurement), area rates of tempered martensite, tempered bainite and ferrite (area of whole photograph is 100%) described below become an index.

[0022] Tempered martensite or tempered bainite: 20% by area or larger (e.g. 25% by area or larger, or 30% by area or larger), 90% by area or smaller (e.g. 65% by area or smaller, or 50% by area or smaller)

[0023] Ferrite: 0% by area or larger (e.g. 10% by area or larger, or 15% by area or larger), 60% by area or smaller (e.g. 50% by area or smaller, or 40% by area or smaller)

[0024] Retained austenite is an essential microstructure for exerting TRIP (transformation induced plasticity) effect, and is useful for improving a total elongation. An amount of retained austenite can be measured by a saturated magnetization measuring method and, letting a total to be 100%, 5% by volume or larger (preferably 8% by volume or larger, further preferably 10% by volume or larger) is desirable. However, when retained austenite becomes too much, stretch-flanging property (hole enlarging rate) tends to deteriorate, therefore, retained austenite is desirably 40% by volume or smaller (preferably 30% by volume or smaller, further preferably 20% by volume or smaller).

[0025] In the conventional TRIP steel sheet, retained austenite is present in an old austenite grain boundary in a random orientation, while in the present invention, there is also characteristic that retained austenite is present in a substantially same orientation along a block boundary in the same packet.

[0026] Although it is desirable that the matrix and the second phase are substantially formed of the aforementioned microstructure, other microstructures (perlite, tempered bainite when the matrix is a tempered martensite, tempered martensite when the matrix is a tempered bainite) inevitably remaining in a manufacturing step, and precipitates are allowable.

[0027] In the steel sheet of the present invention, it is desirable that the retained austenite is lath-like (needle-like) form. The reason is that TRIP steel sheet having lath-like retained austenite not only has TRIP (transformation induced plasticity) effect equivalent to that of TRIP steel sheet having spherical retained austenite, but also further remarkable effect of improving stretch-flanging property is recognized. It is desirable that lath-like retained austenite having a long axis/short axis ratio of 3 or larger is, for example, 60% by area or larger, preferably 65% by area or larger, further preferably 70% by area or larger relative to total retained austenite.

[Component]

[0028] Then, chemical components of the steel sheet of the present invention will be explained. Hereinafter, all of units of chemical components mean % by mass.

C: 0.10 to 0.6%

[0029] C is an essential element for securing a high strength, and for securing retained austenite. More particularly, C is an important element for bringing sufficient C into an austenite phase as a solid solution, and making a desired austenite phase remain even at room temperature, and is useful for enhancing balance between strength and stretch-flanging property. An amount of C is 0.10% or larger, preferably 0.13% or larger, further preferably 0.15% or larger. However, when C becomes excessive, not only its effect is saturated, but also defects are easily caused due to central segregation during a casting stage. Therefore, an amount of C is 0.6% or smaller, preferably 0.5% or smaller, further preferably 0.4% or smaller. When an amount of C exceeds 0.3%, weldability tends to decrease. Therefore, it is recommended that an amount of C is 0.3% or smaller, preferably 0.28% or smaller, further preferably 0.25% or smaller also in view of weldability.

Si: 1.0% or smaller (including 0%)

[0030] Si is useful as an element for reinforcing a solid solution, and is an element useful for suppressing production of carbide due to decomposition of retained austenite. However, when Si is too much, surface treating property (phosphoric acid treatment property and galvanizing property) is deteriorated, and additionally, processibility (stretch-flanging property and total elongation) is adversely effected. Therefore,, it is desirable to suppress an amount of Si to at most 1.0% or smaller, more preferably 0.8% or smaller.

Al: 0.3 to 2.0%

[0031] Al is an element useful for suppressing production of carbide due to decomposition of, particularly, retained austenite, and is contained at 0.3% or larger, more preferably 0.5% or larger. However, since when Al is too much, hot shortness easily occurs. Therefore, an amount of Al is 2.0% or smaller, more preferably 1.8% or smaller. Almost all of the conventional TRIP steel sheets including those described in the aforementioned Patent Publications have a content of Al of 0.1% or smaller and, as far as the present inventors know, there has been no TRIP steel sheet in which a content of Al is positively increased to 0.3% or larger at an Example level. The reason seems that it was thought that Al is a source of oxide based inclusions adversely effecting processibility and hot shortness. However, according to study by the present inventors, as will be described in detail below, it was found that a steel sheet in which a content of Al is increased to a 0.3 to 2.0% level gives a TRIP steel sheet exhibiting a high value also in a total elongation and stretch-flinging property while maintaining a high strength, in cooperation with other component composition and microstructure control.

Mn: 1.0 to 3%

[0032] Mn is an element useful for stabilizing austenite, and maintaining retained austenite at a prescribed amount or larger. Therefore, Mn is 1.0% or larger, preferably 1.2% or larger, further preferably 1.3% or larger. On the other hand, when an amount of Mn becomes excessive, it becomes a cause for casting one side cracking. Therefore, an amount of Mn is 3% or smaller, preferably 2.5% or smaller, further preferably 2.0% or smaller.

P: 0.02% or smaller

[0033] P is an element useful for maintaining desired retained austenite, and its effect is exerted by an amount of P of 0.001% or larger, more preferably 0.005% or larger, but when an amount of P is excessive, secondary processibility is deteriorated. Therefore, an amount of P should be suppressed to 0.02% or smaller, preferably 0.015 or smaller.

S: 0.03% or smaller

[0034] S is a harmful element which forms a sulfide based inclusions such as MnS, and becomes an origin of cracking, deteriorating processibility. Therefore, it is desirable to reduce an amount of S as much as possible. Accordingly, S is 0.03% or smaller, preferably 0.01% or smaller, further preferably 0.005% or smaller.
[0035] The steel sheet of the present invention may contain the following components in addition to the aforementioned components.
[0036] At least one selected from Ca: 0.003% or smaller and REM: 0.003% or smaller
[0037] These Ca and REM (rare earth element) are both an element effective for controlling a form of sulfide in the steel, and improving processibility. Examples of the rare earth element include Sc, Y, and lanthanoid. In order that the aforementioned action is effectively exerted, it is recommended that each of them is contained at 0.0003% or larger (particularly 0.0005% or larger). However, even when each of them is added excessively, the effect is saturated and the economical efficiency is reduced. Therefore, it is better to suppress an amount thereof to 0.003% or smaller (particularly 0.002% or smaller).
[0038] At least one selected from Nb: 0.1% or smaller, Ti: 0.1% or smaller, and V: 0.1% or smaller
[0039] These Nb, Ti and V have the effect of strengthening precipitation and finely dividing a microstructure, and are an element useful for highly strengthening. In order that such the action is effectively exerted, it is recommended that each of them is contained at 0.01% or larger (particularly 0.02% or larger). However, even when each of them is added excessively, the effect is saturated and economical efficiency is reduced. Therefore, an amount of each of them is 0.1% or smaller (preferably 0.08% or smaller, further preferably 0.05% or smaller).
[0040] At least one is selected from Mo: 2% or smaller, Ni: 1% or smaller, Cu: 1% or smaller, and Cr: 2% or smaller
[0041] These Mo, Ni, Cu and Cr are useful as an element for reinforcing the steel, and at the same time, are elements having similarly effectiveness useful for stabilizing retained austenite. In order that such the action is effectively exerted, it is better that each of them is contained at 0.05% or larger (particularly 0.1% or larger). However, even when each of them is added excessively, the effect is saturated and is not economical. Therefore, an amount of Mo and Cr each is 2% or smaller (preferably 1% or smaller, more preferably 0.8% or smaller), and an amount of Ni and Cu each is 1% or smaller (preferably 0.5% or smaller, more preferably 0.4% or smaller).
[0042] The steel sheet of the present invention may further contain other elements as far as the aforementioned microstructure characteristic is satisfied, or a remaining part may be Fe and inevitable impurities.
[0043] The steel sheet of the present invention is constructed of specified components and specified microstructures as described above and, as other characteristic factor, it becomes important for improving balance between a strength, a total elongation, and stretch-flanging property (hole enlarging rate) to a far higher level that a relationship between a carbon amount (C: % by mass) in the steel, a volume rate ($f\gamma R$) of the aforementioned retained austenite and a carbon concentration ($C\gamma R$) in the aforementioned retained austenite satisfies a relationship of the following equation (I):

$$(f\gamma R \times C\gamma R) / C \geq 50 \qquad \text{(I)}$$

[0044] When a value of the (I) equation is less than 50, a strength exhibits a high value, but a total elongation and stretch-flanging property are reduced as can be confirmed also in Examples below, and an object of the present invention is not achieved. A more preferably value of the (I) equation is 55 or more.
[0045] Incidentally, $f\gamma R$ represents an amount of retained austenite, $C\gamma R$ is an index for showing stability of the retained austenite and, when a value of ($f\gamma R \times C\gamma R$) is higher, a larger amount of more stable retained austenite is present, and plasticity organic transformation (TRIP) effect is effectively exerted. Therefore, when this value is relatively larger relative to C, and a value of the equation (I) is large (50 or larger), it is thought that this is an important factor for enhancing a total elongation and stretch-flanging property.
[0046] In the steel sheet of the present invention, by satisfying the specified microstructures and the specified components described-above, and maintaining a value of the (I) equation of 50 or larger, a strength, a total elongation, and stretch-flanging property (hole enlarging rate) are balanced at an extremely high level. And, the steel sheet of the present invention satisfying the aforementioned factors, even when a tensile strength is 750 to 1050MPa (that is, around 780MPa to around 980MPa), have both of excellent total elongation and excellent stretch-flanging property (hole enlarging rate), for example, it also becomes possible that a tensile strength (TS), a total elongation (E1), and a

hole enlarging rate (λ) satisfy a relationship of the following equation:

$$TS \times E1 \geq 22{,}000, TS \times \lambda \geq 20{,}000$$

[wherein TS represents result of measurement of a tensile strength (unit: MPa), E1 represents result of measurement of a total elongation (unit: %), and γ represents result of measurement of hole enlarging rate (unit: %)].

[0047] The steel sheet of the present invention satisfying the aforementioned defining requirements stably exhibits excellent processibility due to an appropriate composition and a metal microstructure thereof. Its property is of course effectively exerted as a naked steel sheet, and additionally, its characteristic is sufficiently exerted as a surface-treated steel sheet which has been subjected to, for example, phosphate treatment, or as a plated steel sheet which has been subjected to, for example, plating treatment such as melting-galvanizing, further, alloy heating treatment.

[Manufacturing process]

[0048] The aforementioned TRIP steel sheet of the present invention can be manufactured by cold rolling a steel sheet (a composition of components is common with that of TRIP steel sheet) with a martensite (not tempered martensite; quenched martensite) or a bainite (not tempered bainite) introduced therein at rolling reduction rate of 30% or smaller, and thereafter, or without performing cold rolling, soaking (or uniformly heating) at a ferrite-austenite 2 phase region temperature and retaining at a temperature region of 450 to 550°C for 10 to 500 seconds.

[0049] When a steel sheet with a martensite or a bainite introduced therein (including a steel sheet having a martensite-ferrite, or bainite-ferrite) is burned at a 2 phase region, and thereafter, retained at a predetermined temperature region for a predetermined time, a second phase (phase containing retained austenite) different from a matrix (tempered martensite, tempered bainite etc.) can be produced. And, when cold rolling is performed under an appropriate condition prior to this heat treatment, an appropriate second phase (phase containing retaining austenite) can be formed at the heat treatment, and consequently, a total elongation and stretch-flanging property (hole enlarging rate) can be remarkably improved. It is better that a rolling reduction rate at this time is specifically set around 0% or larger (preferably 5% or larger, further preferably 10% or larger), and 30% or smaller (preferably 25% or smaller, further preferably 20% or smaller).

[0050] Meanwhile, the aforementioned rolling reduction rate contributes also to increase an amount of lath-like retained austenite, and as rolling reduction rate grows smaller, an amount of lath-like retained austenite is increased. In the present invention, since rolling reduction rate is defined as described above, it is difficult to drastically change an amount of lath-like austenite by greatly changing rolling reduction rate. However, when it is intended to increase an amount of lath-like retained austenite, smaller rolling reduction rate may be selected from the relevant range, or cold-rolling may be omitted in some cases.

[0051] A steel sheet with a martensite or a bainite introduced therein can be obtained by a conventional method. That is, by rapidly cooling a temperature of a steel sheet heated to an austenite region to a temperature of Ms point or lower, a martensite can be introduced. And, by rapidly cooling a temperature of the steel sheet to a temperature of not lower than Ms point and not higher than Bs point, and thereafter, transforming the steel sheet at a constant temperature, a bainite can be introduced. In addition, a ferrite can be introduced by setting a cooling pattern so that the steel sheet passes through a ferrite transformation region in a continuous cooling transformation curve (CCT curve). Since a perlite is not desirable in the present invention, it is desired to set a cooling pattern so that a perlite transformation region is avoided.

[0052] Meanwhile, when an object is to produce a martensite or a bainite, a method of rapidly cooling to a predetermined temperature monotonously is simple, but when it is intended to produce also a ferrite, since it is difficult to stably introduce a ferrite by monotonous cooling, it is better to adopt a multistage cooling method of setting a cooling rate by dividing into plural times. In particular, a method of retaining an austenite-ferrite 2 phase region temperature and initiating cooling again is recommended. When any of the aforementioned cooling patterns is adopted, it is recommended that a cooling rate is, for example, 10°C/sec or larger (preferably 20°C/sec or larger).

[0053] In view of practical operation, it is effective to perform introduction of a martensite or a bainite during a cooling process after hot rolling. In this case, it is recommended to adjust a hot-rolling finishing temperature (FDT) to around (Ar3-50) °C and to cool a steel by any of aforementioned various cooling patterns and then roll up it at a temperature of a Ms point or lower (in the case of introduction of a martensite), or a temperature of not lower than Ms point and not larger than Bs point (in the case of introduction of a bainite). A hot rolling starting temperature (SRT) can be selected from such a range that the aforementioned finishing temperature can be maintained, and is, for example, around 1000 to 1300°C.

[0054] Heat-treating method after cold rolling will be explained in further detail as follows:

[0055] Heating to a ferrite-austenite 2 phase region temperature (not lower than an A1 point and not higher than an

A3 point) is for the purpose of producing an austenite while leaving a martensite and a bainite. A heating time at the 2 phase region temperature can be appropriately selected depending on a setting amount of each of tempered martensite, tempered bainite and retained austenite in a desired TRIP steel sheet, and is different depending on a heating temperature and a cooling rate thereafter, therefore, it is difficult to equally define, but can be selected from a range of, for example, 10 seconds or longer (preferably 20 seconds or longer, further preferably 30 seconds or longer) and 600 seconds or shorter (preferably 500 seconds or shorter, further preferably 400 seconds or shorter). When a heating time is too short, a retained austenite is deficient and, when a heating temperature is too long, a tempered martensite, or a tempered bainite is deficient (or a lath-like microstructure, which is characteristic in tempered martensite and tempered bainite, is damaged), and at the same time, a retained austenite becomes coarse, or easily degrade to carbide.

[0056] Rapid cooling from a 2 phase region temperature is for the purpose of avoiding ferrite transformation, perlite transformation and bainite transformation. Specifically, a steel sheet is cooled at such a rate that a Fs line, a Ps line or a Bs line in a CCT curve can be avoided (e.g. rate of 3°C/sec or larger, preferably around 5°C/sec or larger).

[0057] Then, cooling to a temperature of 450°C or higher (preferably 470°C or higher) and 550°C or lower (preferably 530°C or lower) and thereafter retaining at the temperature region is for the purpose of securing an amount of retained austenite by lowering a Ms point of an austenite phase. A time for soaking at the temperature region is appropriately set depending on an amount of an austenite produced at the 2 phase region temperature and an amount of retained austenite to be set in a desired TRIP steel sheet, and at least 10 seconds or longer (preferably 50 seconds or longer) should be secured. However, when an austemper time is too long, bainite transformation proceeds and an amount of retained austenite is reduced. Therefore, the time should be suppressed to 500 seconds or shorter, more preferably 200 seconds or shorter.

[0058] In view of actual operation, the aforementioned heat treatment after cold rolling is conveniently performed by using continuous annealing facilities. In addition, when the cold rolled sheet is subjected to galvanizing, for example, melting-galvanizing, it is possible to perform melting-galvanization after heat-treatment under the aforementioned appropriate condition, and further perform its alloy heat-treatment. Further, it is also possible to set so that a part of galvanizing condition or its alloy heat-treating condition satisfies the aforementioned heat treatment condition, and perform the aforementioned heat-treatment at the plating step.

[0059] Since the thus obtained steel sheet of the present invention and its melting-galvanized article are excellent in not only a strength but also a total elongation and stretch-flanging property, they can be easily processed. For this reason, steel parts having a high strength can be provided.

Examples

[0060] The following Examples illustrate the present invention more specifically, but the present invention is not restricted by the following Examples, the present invention can be of course practiced by appropriate variation in such a range that the above-and later-descried gist is adopted, and they are all included in the technical scope of the present invention.

Example 1

[0061] A test steel having a component composition described in the following Table 1 (unit is % by mass in Table) was melted in vacuum and produced into an experimental slab having a thickness of 20 to 30 mm and, thereafter, manufactured into a hot rolled-sheet having a sheet thickness of 2.5mm by a hot rolling-1 stage (monotonous) cooling pattern shown in Fig. 1 or a hot rolling-2 stage cooling pattern shown in Fig. 2, which was further cold rolled to manufacture a cold rolled sheet having a sheet thickness of 2.0 mm. This cold rolled sheet was heated to a ferrite-austenite 2 phase region temperature (830°C), burned by retaining for 120 seconds, and subjected to heat-treatment by rapidly cooling to a predetermined temperature and retaining for a predetermined time, to manufacture a TRIP steel sheet. Symbols in Fig. 1 and Fig. 2 have the following meanings:

SRT: hot rolling heating temperature
FDT: hot rolling finishing temperature
CR1: cooling rate at first stage
CTN: retaining temperature after cooling at first stage
CR2: cooling rate at second stage
CT: rolling up temperature

[0062] Conditions of the aforementioned hot rolling-1 stage or 2 stage cooling, a microstructure of hot rolled sheet, rolling reduction rate during cold rolling, soaking temperature, an austemper temperature and an austemper time are

shown in the following Tables 2, 4 and 6. A microstructure of the resulting TRIP steel sheet, a value of the equation (I), a tensile strength (TS), a total elongation (E1), stretch-flanging property (hole enlarging rate: λ), and phosphoric acid treating property are shown in the following Tables 3, 5 and 7.

[0063] In addition, from data of the following Tables 2 to 7, regarding some samples having different Al contents, effect of an austemper temperature and an austemper time after hot rolling and cold rolling, and then, soaking on a value of the equation (I) are shown in Figs. 3 and 4, and similarly, effect of an austemper temperature and an austemper time after the same soaking on an amount of retained austenite is shown in Figs. 5 and 6.

[0064] Microstructures of hot rolled sheets and TRIP steel sheets shown in the aforementioned Tables 2 to 7 were investigated as follows: That is, the steel sheets were Lepera-etched, the microstructures were identified by observation with a transmission electron microscope (TEM; 15,000-fold magnification), and an area rate of each of tempered martensite, tempered bainite and ferrite was calculated based on an optical microscope photograph (1,000-fold magnification). In addition, a ratio of lath-like retained austenite (retained austenite having a long axis/short axis ratio of 3 or larger) relative to total retained austenite was also measured based on the optical microscope photograph. On the other hand, a volume rate of retained austenite was measured by measurement of saturated magnetization [see JP-A No. 2003-90825, and "R & D Kobe Seiko Giho" Vol.52, No. 3 (Dec. 2002)], and a C concentration in retained austenite was measured with a X-ray microanalyzer (XMA) after grinding of a steel sheet to a 1/4 thickness and chemical polishing (ISIJ Int. Vol.33, 1993, No. 7, P.776).

[0065] A tensile strength (TS) and a total elongation (E1) were measured using JIS No. 5 test pieces, and stretch-flanging property was assessed by preparing test pieces having a diameter of 100 mm and a sheet thickness of 2.0 mm, subjecting a central part of the piece to punching procession to perforate a hole having a diameter of 10 mm, then subjecting to hole enlarging procession with a 60° conical punching on a burr, and measuring a hole enlarging rate (λ) at a crack penetrating time (JFST1001; Standard from The Japan Iron and Steel Federation).

[0066] In addition, phosphoric acid treating property and Fe concentration in galvanizing were obtained by the following manners.

[Phosphoric acid treating property]

[0067] Each test steel sheet is immersed in a phosphate treating solution (trade name "LB-L3020" manufactured by Nihon Parkerizing Co., Ltd) at 43°C for 2 minutes, pulled out, and dried, and then a surface thereof is observed with SEM (2,000-fold magnification) to investigate status of attachment of phosphate crystal. Separately, test steel sheets which have been subjected to phosphate treatment are immersed in a solution of [20 g of ammonium bichromate + 490 g of aqueous ammonia + 490 g of water] at room temperature for 15 minutes, pulled out, and dried, and an amount of attachment of phosphate is obtained from a difference in weights before and after immersion. From the aforementioned test results, phosphate treatment property is assessed on a scale of 3-stages according to the following criteria:

◎ : Phosphate crystals are attached to a whole surface without gap, and an amount of attachment of phosphate is 4 g/m^2 or larger.

o: Phosphate crystals are attached to an almost all region of a surface without gap, and an amount of attachment of phosphate is not smaller than 3 g/m^2 and smaller than 4 g/m^2.

×: A part to which no phosphate crystal is attached is observed in a part of a surface, and an amount of attachment of phosphate is smaller than 3 g/m^2.

[Alloy-galvanizing property]

[0068] After each test steel sheet is immersed in a melted zinc bath, alloy heat-treatment is performed at 550°C for 60 seconds. A plated layer of the resulting alloy-galvanized steel sheet is dissolved with hydrochloric acid, and a content of Zn and that of Fe in the solution are quantitatively analyzed by ICP, whereby, the Fe concentration in alloy-galvanizing is obtained. A Fe concentration in a range of 8 to 13% is normal, and it is determined that alloying proceeds sufficiently (better), and a concentration of smaller than 8% is determined to be worse.

Table 1

Steel No.	C	Si	Mn	P	S	Al	Others
1	0.08	0.48	1.48	0.012	0.002	1.02	
2	0.10	0.49	1.52	0.013	0.001	1.03	
3	0.18	0.51	1.51	0.011	0.001	1.02	
4	0.25	0.50	1.51	0.010	0.002	0.998	

Table 1 (continued)

Steel No.	C	Si	Mn	P	S	Al	Others
5	0.40	0.51	1.51	0.011	0.002	1.01	
6	0.48	0.52	1.52	0.011	0.001	0.999	
7	0.58	0.49	1.53	0.012	0.002	1.01	
8	0.20	0.03	1.49	0.008	0.001	1.00	
9	0.20	0.10	1.51	0.010	0.002	1.02	
3	0.18	0.51	1.51	0.011	0.001	1.02	
10	0.20	0.79	1.48	0.010	0.001	1.01	
11	0.20	1.29	1.50	0.012	0.002	0.99	
12	0.19	0.51	1.01	0.010	0.001	0.997	
3	0.18	0.51	1.51	0.011	0.001	1.02	
13	0.21	0.49	2.05	0.011	0.002	1.03	
14	0.20	0.51	2.51	0.009	0.002	1.00	
15	0.20	0.49	2.82	0.010	0.002	1.04	
3	0.18	0.51	1.51	0.011	0.001	1.02	
16	0.19	0.51	1.53	0.015	0.002	1.00	
17	0.21	0.50	1.52	0.021	0.002	1.00	
3	0.18	0.51	1.51	0.011	0.001	1.02	
18	0.21	0.52	1.50	0.009	0.012	1.03	
19	0.20	0.49	1.50	0.010	0.023	1.01	
20	0.19	0.49	1.49	0.011	0.030	1.02	
21	0.20	0.52	1.49	0.010	0.002	0.03	
22	0.20	0.51	1.48	0.011	0.002	0.34	
23	0.21	0.52	1.49	0.010	0.001	0.70	
3	0.18	0.51	1.51	0.011	0.001	1.02	
24	0.20	0.50	1.49	0.010	0.001	1.85	
25	0.20	0.49	1.51	0.010	0.001	1.01	Nb:0.03
26	0.20	0.51	1.52	0.011	0.002	1.03	Mo:0.3
27	0.20	0.52	1.53	0.010	0.001	0.998	Cr:0.3
28	0.20	0.51	1.51	0.012	0.001	0.999	Ca:20 ppm
29	0.20	1.32	1.52	0.010	0.002	0.032	

Table 2

Experiment No.	Steel No.	Hot rolling·cooling				Hot rolled·sheet	Cold rolling	Soaking (°C)	Aus·temper temp. (°C)	Aus·temper time (s)
		SRT (°C)	FDT (°C)	CR1 (°C/s)	CT (°C)	Hot rolled·microstructure	Rolling reduction rate (%)			
1	1	1200	880	50	400	B	20	830	470	100
2	2	1200	880	50	400	B	20	830	470	100
3	3	1200	880	50	400	B	20	830	470	100
4	4	1200	880	50	400	B	20	830	470	100
5	5	1200	880	50	400	B	20	830	470	100
6	6	1200	880	50	400	B	20	830	470	100
7	7	1200	880	50	400	B	20	830	470	100
8	8	1200	880	50	400	B	20	830	470	100
9	9	1200	880	50	400	B	20	830	470	100
3	3	1200	880	50	400	B	20	830	470	100
10	10	1200	880	50	400	B	20	830	470	100
11	11	1200	880	50	400	B	20	830	470	100
12	12	1200	880	50	400	B	20	830	470	100
3	3	1200	880	50	400	B	20	830	470	100
13	13	1200	880	50	400	B	20	830	470	100
14	14	1200	880	50	400	B	20	830	470	100
15	15	1200	880	50	400	B	20	830	470	100
3	3	1200	880	50	400	B	20	830	470	100
16	16	1200	880	50	400	B	20	830	470	100
17	17	1200	880	50	400	B	20	830	470	100
3	3	1200	880	50	400	B	20	830	470	100
18	18	1200	880	50	400	B	20	830	470	100
19	19	1200	880	50	400	B	20	830	470	100
20	20	1200	880	50	400	B	20	830	470	100

Table 2 (continued)

21	21	1200	880	50	400	B	20	830	470	100
22	22	1200	880	50	400	B	20	830	470	100
23	23	1200	880	50	400	B	20	830	470	100
3	3	1200	880	50	400	B	20	830	470	100
24	24	1200	880	50	400	B	20	830	470	100
25	25	1200	880	50	400	B	20	830	470	100
26	26	1200	880	50	400	B	20	830	470	100
27	27	1200	880	50	400	B	20	830	470	100
28	28	1200	880	50	400	B	20	830	470	100
29	29	1200	880	50	600	F·P	20	830	470	100

Table 3

Experiment No.	TRIP steel sheet													
	Microstructure (%)					$C_{\gamma R}$ (%)	$f_{\gamma R}$ (%)	C (%)	$(C_{\gamma R} \times f_{\gamma R})/C$	TS (Mpa)	El (%)	λ (%)	Phosphoric acid treating property	Concentration of Fe in Zn
	F	TM	TB	Others	Lath-like γR/total γR (%)									
1	0	·	93	3	20	0.66	4	0.08	30	590	19	15	○	10
2	0	·	90	4	30	0.75	6	0.10	45	600	18	31	○	9
3	0	·	84	5	75	1.06	11	0.18	65	790	32	50	○	10
4	0	·	83	5	78	1.31	12	0.25	63	790	33	49	○	11
5	0	·	76	3	80	1.33	21	0.40	70	980	29	35	○	10
6	0	·	78	4	79	1.28	28	0.53	68	1010	25	38	○	11
7	0	·	65	3	79	1.31	32	0.58	72	1310	20	35	○	11
8	0	·	86	3	80	1.29	11	0.20	71	785	33	51	◎	10
9	0	·	86	2	76	1.16	12	0.20	70	800	34	52	◎	12
3	0	·	86	3	77	1.06	11	0.18	65	810	32	50	○	11
10	0	·	86	2	78	1.06	10	0.20	53	815	31	48	○	10
11	0	·	86	3	82	1.05	11	0.20	58	820	31	47	×	0
12	0	·	84	3	79	1.05	13	0.18	72	730	35	61	○	11
3	0	·	86	3	82	1.06	11	0.18	65	790	32	50	○	10
13	0	·	84	2	83	1.05	14	0.21	70	810	30	45	○	11
14	0	·	84	3	80	1.09	13	0.20	71	980	27	39	○	12
15	0	·	83	3	82	1.03	14	0.20	72	995	28	36	○	10
3	0	·	86	3	83	1.06	11	0.18	65	790	32	50	○	10
16	0	·	86	2	84	1.01	12	0.19	64	810	31	59	○	11
17	0	·	84	3	85	1.02	13	0.21	63	820	31	48	○	12
3	0	·	86	3	80	1.06	11	0.18	65	790	32	50	○	10
18	0	·	87	2	77	1.30	11	0.21	68	785	33	48	○	12
19	0	·	86	2	79	1.15	12	0.20	69	790	32	44	○	11
20	0	·	86	3	74	1.16	11	0.19	67	787	31	43	○	11

Table 3 (continued)

21	0	-	95	3	-	-	2	0.20	-	795	25	30	o	10
22	0	-	95	3	-	-	2	0.20	-	794	23	39	o	10
23	0	-	87	3	74	1.45	10	0.21	69	793	30	45	o	11
3	0	-	86	3	78	1.06	11	0.18	65	790	32	50	o	12
24	0	-	83	3	74	0.98	14	0.20	69	794	33	59	o	12
25	0	-	83	3	81	1.04	14	0.20	73	980	23	45	o	11
26	0	-	82	4	82	1.03	14	0.20	72	990	28	48	o	12
27	0	-	85	2	80	1.12	13	0.20	73	985	29	49	o	10
28	0	-	83	3	81	1.03	14	0.20	72	790	30	48	o	10
29	0	-	-	14	25	0.66	12	0.2	40	790	27	23	x	3

Table 4

Experiment No.	Steel No.	Hot rolling-cooling						Hot rolled-sheet	Cold rolling	Soaking (°C)	Aus-temper temp. (°C)	Aus-temper time (s)
		SRT (°C)	FDT (°C)	CR1 (°C/s)	CTN (°C)	CR2 (°C/s)	CT (°C)	Hot rolled-microstructure	Rolling reduction rate (%)			
30	3	1200	880	50	-	-	400	B	20	700	470	100
31	3	1200	880	50	-	-	400	B	20	800	470	100
32	3	1200	880	50	-	-	400	B	20	830	470	100
33	3	1200	880	50	-	-	400	B	20	860	470	100
34	3	1200	880	50	-	-	400	B	20	900	470	100
35	3	1200	880	50	-	-	400	B	20	830	470	100
36	3	1200	880	50	-	-	400	B	20	830	430	100
37	3	1200	880	50	-	-	400	B	20	830	470	100
38	3	1200	880	50	-	-	400	B	20	830	500	100
39	3	1200	880	50	-	-	400	B	20	830	530	100
40	3	1200	880	50	-	-	400	B	20	830	560	100
41	3	1200	880	50	800	50	100	M	20	830	470	100
42	3	1200	880	50	700	50	100	F·M	20	830	470	100
43	3	1200	880	50	600	50	100	F·M	20	830	470	100
44	3	1200	880	50	800	50	400	B	20	830	470	100
45	3	1200	880	50	700	50	400	F·B	20	830	470	100
46	3	1200	880	50	600	50	400	F·B	20	830	470	100
47	8	1200	880	50	-	-	400	B	20	830	400	100
48	8	1200	880	50	-	-	400	B	20	830	430	100
49	8	1200	880	50	-	-	400	B	20	830	470	100
50	8	1200	880	50	-	-	400	B	20	830	500	100
51	8	1200	880	50	-	-	400	B	20	830	530	100
52	8	1200	880	50	-	-	400	B	20	830	560	100

Table 5

Experiment No.	TRIP steel sheet													
	Microstructure (%)					$C_{\gamma R}$ (%)	$f_{\gamma R}$ (%)	C (%)	$(C_{\gamma R} \times f_{\gamma R})/C$	TS (Mpa)	EI (%)	λ (%)	Phosphoric acid treating property	Concentration of Fe in Zn
	F	TM	TB	Others	Lath-like γR/total γR (%)									
30	-	-	95	3	77	0.90	2	0.18	10	800	20	30	◎	11
31	-	-	86	4	79	1.21	10	0.18	67	800	31	45	◎	12
32	-	-	83	4	80	0.90	13	0.18	65	790	32	55	◎	10
33	-	-	84	3	73	0.90	13	0.18	65	795	32	50	◎	11
34	-	-	88	4	74	1.12	9	0.18	56	790	30	30	◎	12
35	-	-	89	3	75	0.90	8	0.18	40	805	20	30	◎	11
36	-	-	90	3	80	0.90	7	0.18	35	800	21	32	◎	10
37	-	-	83	4	82	1.23	13	0.18	93	795	27	55	◎	9
38	-	-	81	4	81	1.29	15	0.18	108	799	32	50	◎	10
39	-	-	87	3	79	1.10	10	0.18	61	795	33	53	◎	11
40	-	-	89	3	74	0.79	8	0.18	35	790	30	28	◎	10
41	0	84	-	4	77	1.10	12	0.18	73	795	30	40	◎	9
42	37	46	-	4	78	1.11	13	0.18	80	790	32	48	◎	9
43	40	48	-	3	82	1.05	12	0.18	70	800	33	40	◎	10
44	0	-	83	3	83	1.05	14	0.18	81	800	30	48	◎	10
45	43	-	41	4	81	1.02	12	0.18	68	790	29	40	◎	10
46	40	-	43	4	82	0.98	13	0.18	71	795	30	45	◎	11
47	-	-	92	3	79	1.44	5	0.20	36	790	20	30	◎	10
48	-	-	87	3	78	1.08	10	0.20	54	799	20	27	◎	9
49	-	-	84	3	77	1.00	13	0.20	65	800	27	55	◎	9
50	-	-	80	4	79	1.12	16	0.20	89	795	32	56	◎	10
51	-	-	84	4	80	1.22	10	0.20	61	800	31	50	◎	10
52	-	-	83	3	82	0.90	4	0.20	18	800	27	25	◎	10

Table 6

Experiment No.	Steel No.	Hot rolling·cooling						Hot rolled·sheet	Cold rolling	Soaking (°C)	Aus·temper temp. (°C)	Aus·temper time (s)
		SRT (°C)	FDT (°C)	CR1 (°C/s)	CTN (°C)	CR2 (°C/s)	CT (°C)	Hot rolled microstructure	Rolling reduction rate (%)			
53	8	1200	880	50	-	-	400	B	20	830	470	5
54	8	1200	880	50	-	-	400	B	20	830	470	20
55	8	1200	880	50	-	-	400	B	20	830	470	50
56	8	1200	880	50	-	-	400	B	20	830	470	100
57	8	1200	880	50	-	-	400	B	20	830	470	300
58	8	1200	880	50	-	-	400	B	20	830	470	900
59	29	1200	880	50	-	-	400	B	70	830	370	100
60	29	1200	880	50	-	-	400	B	70	830	400	100
61	29	1200	880	50	-	-	400	B	70	830	430	100
62	29	1200	880	50	-	-	400	B	70	830	470	100
63	29	1200	880	50	-	-	400	B	70	830	500	100
64	29	1200	880	50	-	-	400	B	70	830	530	100
65	29	1200	880	50	-	-	400	B	70	830	560	100
66	3	1200	880	50	700	50	100	F·M	0	830	470	100
67	3	1200	880	50	700	50	100	F·M	10	830	470	100
68	3	1200	880	50	700	50	100	F·M	20	830	470	100
69	3	1200	880	50	700	50	100	F·M	30	830	470	100
70	3	1200	880	50	700	50	100	F·M	40	830	470	100

Table 7

Experiment No.	TRIP steel sheet													
	Microstructure (%)					$C_{\gamma R}$ (%)	$f_{\gamma R}$ (%)	C (%)	$(C_{\gamma R} \times f_{\gamma R})/C$	TS (Mpa)	El (%)	λ (%)	Phosphoric acid treating property	Concentration of Fe in Zn
	F	TM	TB	Others	Lath-like γR/total γR (%)									
53	-	-	84	3	81	1.20	3	0.20	18	799	18	25	◎	10
54	-	-	77	3	82	1.10	10	0.20	55	790	23	35	◎	10
55	-	-	85	4	83	1.09	11	0.20	60	795	30	45	◎	10
56	-	-	83	4	79	1.00	13	0.20	65	800	32	55	◎	11
57	-	-	85	3	78	1.13	12	0.20	68	800	30	50	◎	10
58	-	-	90	4	77	1.20	6	0.20	36	800	15	25	◎	10
59	-	-	86	4	21	0.86	10	0.20	43	790	30	23	◎	1
60	-	-	83	3	30	1.10	14	0.20	77	790	32	24	◎	2
61	-	-	83	4	28	1.11	13	0.20	72	799	27	22	◎	3
62	-	-	87	3	30	0.91	10	0.20	45	800	23	21	◎	2
63	-	-	88	3	31	0.89	9	0.20	41	795	19	23	◎	1
64	-	-	90	3	33	0.90	7	0.20	31	800	17	20	◎	2
65	-	-	92	4	34	0.90	4	0.20	18	800	15	21	◎	1
66	45	37	-	3	83	1.21	15	0.20	91	795	30	48	◎	11
67	44	40	-	3	83	1.11	13	0.20	72	790	32	48	◎	12
68	49	33	-	4	79	1.11	14	0.20	78	800	30	38	◎	13
69	40	42	-	4	79	1.00	14	0.20	70	795	31	36	◎	12
70	49	34	-	4	33	1.00	13	0.20	65	790	25	20	◎	10

[0069] As apparent from Fig. 3, in a conventional type comparative steel sheet having an Al content of 0.03% by mass, as an austempering temperature after soaking grows higher, a value obtained from the equation (I) is decreased approximately linearly, while for inventive steel materials having an Al content exceeding 0.3% by mass as defined in the present invention, a peculiar tendency is exhibited that a value of the equation (I) shows a peak in a region of an austemper temperature of 450 to 550°C. In addition, from Fig. 4, a value of the equation (I) shows a peak at an austemper time between 10 and 500 seconds. And, it is confirmed that a steel sheet adopting such an austemper temperature and austemper time for getting a high value as a value of the equation (I) , has values which are stable at a high level in the tensile strength (TS), the total elongation (EL) and the hole enlarging rate (λ).

[0070] A tendency confirmed by the aforementioned Figs. 3 and 4 is almost the same in a relationship between an amount of retained austenite, an austemper temperature and an austemper time shown in Figs. 5 and 6, and it is seen that in the present invention using a steel material having a relatively high Al content, by setting the retaining temperature at 450 to 550°C and the austemper time at 10 to 500 seconds, an amount of retained austenite of 5% by volume or larger can be obtained.

Example 2

[0071] A test steel having a component composition described in the following Table 8 (unit is % by mass in Table) was melted in vacuum and produced into an experimental slab having a thickness of 20 to 30 mm and, thereafter, manufactured into a hot rolled-sheet having a sheet thickness of 2.5mm by a hot rolling-1 stage (monotonous) cooling pattern and further cold rolled to manufacture a cold rolled sheet having a sheet thickness of 2.0 mm. This cold rolled sheet was heated to a ferrite-austenite 2 phase region temperature (930°C), soaked by retaining for 120 seconds, and subjected to a cooling process, a temperature retaining process and a continuous annealing process by an air cooling as shown in Fig.7 to get a cold rolled steel sheet.

[0072] After each cold rolled steel sheet is retained at 840 °C for 80 seconds and immersed and traveled in a melt zinc bath, an alloy treatment is performed at a predetermined temperature To for a predetermined time to get an alloy - galvanized steel sheet as shown in Fig. 7. All the conditions are shown in Tables 9 and 10.

[0073] The microstructure of the resulting each galvanized steel sheet was observed as shown in Example 1. An area rate of each of tempered martensite, tempered bainite and ferrite and also a ratio of lath-like retained austenite relative to total retained austenite was also measured. On the other hand, a volume rate of retained austenite and a C concentration in retained austenite was measured. The results are totally shown in Table 11.

[0074] A tensile strength (TS), a total elongation (E1) and a hole enlarging rate (λ) were measured and phosphoric acid treating property and Fe concentration in galvanizing were obtained, in the same way as Example 1. The results are totally shown in Table 12.

Table 8

Steel No.	C	Si	Mn	P	S	Al
30	0.20	0.03	2.3	0.01	0.001	1.5
31	0.20	0.03	2.5	0.01	0.001	1.5

Table 9

Experiment No.	Steel No.	Hot Process: Hot rolling-cooling SRT (°C)	FDT (°C)	CR (°C/s)	CT (°C)	Hot rolled-micro-structure	Cold rolling: Rolling reduction rate (%)	CAL Process: Soaking (°C)	Aus-temper temp. (°C)	Aus-temper time (s)	Annealed micro-structure	CGL Process: Soaking (°C)	Aus-temper temp.(To) (°C)	Aus-temper time (s)
71	30	1200	880	50	650	F-P	0	---	---	---	---	840	550	20
72	30	1200	880	80	400	B	0	---	---	---	---	840	550	20
73	30	1200	880	100	200	M	0	---	---	---	---	840	550	20
74	30	1200	880	50	650	F-P	60	930	200	20	M	840	400	20
75	30	1200	880	50	650	F-P	60	930	200	20	M	840	430	20
76	30	1200	880	50	650	F-P	60	930	200	20	M	840	460	20
77	30	1200	880	50	650	F-P	60	930	200	20	M	840	490	20
78	30	1200	880	50	650	F-P	60	930	200	20	M	840	520	20
79	30	1200	880	50	650	F-P	60	930	200	20	M	840	550	20
80	30	1200	880	50	650	F-P	60	930	200	20	M	840	580	20
81	30	1200	880	50	650	F-P	60	930	200	20	M	840	550	5
82	30	1200	880	50	650	F-P	60	930	200	20	M	840	550	10
83	30	1200	880	50	650	F-P	60	930	200	20	M	840	550	60
84	31	1200	880	50	650	F-P	60	930	200	20	B	840	400	20
85	31	1200	880	50	650	F-P	60	930	200	20	B	840	430	20
86	31	1200	880	50	650	F-P	60	930	200	20	B	840	460	20
87	31	1200	880	50	650	F-P	60	930	200	20	B	840	490	20
88	31	1200	880	50	650	F-P	60	930	200	20	B	840	520	20
89	31	1200	880	50	650	F-P	60	930	200	20	B	840	550	20
90	31	1200	880	50	650	F-P	60	930	200	20	B	840	580	20
91	31	1200	880	50	650	F-P	60	930	200	20	B	840	550	5
92	31	1200	880	50	650	F-P	60	930	200	20	B	840	550	10
93	31	1200	880	50	650	F-P	60	930	200	20	B	840	550	60

Table 10

		Hot Process						CAL Process				CGL Process		
Experiment No.	Steel No.	Hot rolling-cooling				Hot rolled-micro-structure	Cold rolling	Soaking (°C)	Aus-temper temp. (°C)	Aus-temper time (s)	Annealed micro-structure	Soaking (°C)	Aus-temper temp.(To) (°C)	Aus-temper time (s)
		SRT (°C)	FDT (°C)	CR (°C/s)	CT (°C)		Rolling reduction rate (%)							
94	30	1200	880	50	650	F-P	60	930	400	20	B	840	400	20
95	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	430	〃
96	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	460	〃
97	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	490	〃
98	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	520	〃
99	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	550	〃
100	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	580	〃
101	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	550	5
102	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	550	10
103	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	550	60
104	30	1200	880	50	650	F-P	60	930	650	20	F-P	840	400	20
105	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	430	〃
106	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	460	〃
107	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	490	〃
108	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	520	〃
109	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	550	〃
110	30	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	〃	580	〃

Table 11

		Microstructure					retained γ property		
Experiment No.	Steel No.	F	TM	TB	Others	Lath-like γ R/total γ R (%)	$C\gamma_R$ (%)	$f\gamma_R$ (%)	$(C\gamma_R \times f_{\gamma R})/C$
71	30	40	-	-	3	40	1.0	9	45
72	30	-	-	83	4	80	1.2	13	78
73	30	-	78	-	3	73	1.3	14	91
74	30	2	80	-	2	81	1.3	11	72
75	30	3	83	-	3	78	1.2	12	72
76	30	1	79	-	2	79	1.3	15	98
77	30	2	81	-	3	78	1.3	15	98
78	30	2	79	-	1	77	1.3	15	98
79	30	3	80	-	2	76	1.3	14	91
80	30	1	81	-	3	79	1.4	13	91
81	30	2	82	-	2	80	0.8	11	44
82	30	2	81	-	1	81	1.4	13	91
79	30	3	80	-	2	76	1.3	14	91
83	30	1	84	-	2	81	1.3	12	78
84	31	2	78	-	2	78	1.2	11	66
85	31	3	81	-	3	77	1.1	12	66
86	31	5	79	-	2	76	1.2	13	78
87	31	0	80	-	2	78	1.3	13	85
88	31	3	81	-	3	79	1.2	13	78
89	31	2	80	-	2	76	1.1	13	72
90	31	4	80	-	1	75	1.2	14	84
91	31	0	78	-	2	78	0.8	11	44
92	31	3	79	-	3	76	1.3	12	78
89	31	2	80	-	2	76	1.1	13	72
93	31	2	80	-	4	77	1.4	12	84
94	30	2	-	80	2	70	1.1	12	66
95	30	3	-	79	3	68	1.2	11	66
96	30	2	-	78	2	67	1.2	13	78
97	30	2	-	81	3	70	1.2	14	84
98	30	2	-	79	4	71	1.3	12	78
99	30	1	-	78	3	69	1.4	11	77
100	30	0	-	77	2	68	1.3	13	85
101	30	1	-	79	1	67	0.8	12	48
102	30	2	-	80	3	66	1.2	11	66
99	30	1	-	78	3	69	1.4	11	77
103	30	3	-	76	2	68	1.3	12	78
104	30	2	-	77	1	40	1.2	11	66
105	30	3	-	76	2	38	1.1	12	66
106	30	1	-	78	3	47	1.1	8	44
107	30	0	-	77	2	38	1.0	9	45
108	30	2	-	76	1	37	1.1	7	39
109	30	1	-	75	2	33	1.0	7	35
110	30	1	-	73	2	25	1.0	6	30

Table 12

		mechanical property			Surface property		
Experiment No.	Steel No.	TS (MPa)	El(%)	λ (%)	Phosphoric acid treating property	Concentration of Fe in Zn	Total valuation
71	30	801	20	18	◎	12	×
72	30	802	28	30	◎	11	◎
73	30	804	26	25	◎	13	◎
74	30	803	28	37	◎	2	×
75	30	802	29	32	◎	4	×
76	30	801	28	30	◎	9	○
77	30	800	25	28	◎	12	○
78	30	804	26	27	◎	11	◎
79	30	798	26	27	◎	10	◎
80	30	803	25	26	◎	11	◎
81	30	890	22	17	◎	6	×
82	30	801	23	26	◎	11	◎
79	30	798	26	27	◎	12	◎
83	30	802	25	28	◎	11	◎
84	31	810	28	36	◎	2	×
85	31	808	29	32	◎	3	×
86	31	812	28	30	◎	9	◎
87	31	890	27	28	◎	12	◎
88	31	810	25	27	◎	11	◎
89	31	790	27	27	◎	13	◎
90	31	790	26	26	◎	12	◎
91	31	880	22	18	◎	13	×
92	31	803	26	27	◎	11	◎
89	31	790	27	27	◎	12	◎
93	31	802	27	28	◎	11	◎
94	30	790	29	30	◎	3	×
95	30	770	30	30	◎	4	×
96	30	790	30	25	◎	9	◎
97	30	820	27	24	◎	12	◎
98	30	820	27	25	◎	11	◎
99	30	820	27	24	◎	13	◎
100	30	800	27	28	◎	12	◎
101	30	870	22	18	◎	14	×
102	30	800	27	26	◎	12	◎
99	30	820	27	24	◎	11	◎
103	30	802	28	28	◎	12	◎
104	30	802	25	23	◎	2	×
105	30	798	26	23	◎	5	×
106	30	808	26	21	◎	9	×
107	30	805	24	20	◎	12	×
108	30	811	23	18	◎	11	×
109	30	812	22	20	◎	13	×
110	30	800	24	24	◎	12	×

[0075] Figs. 8, 9 and 10 were made from the results of Tables 7 to 11 and show the relation (Fig. 10) between the

retained γ property and the alloy heat treatment temperature of alloy-galvanized steel sheet which causes the mechanical properties of a tensile strength (TS) and a total elongation (E1) and a hole enlarging rate (λ).

[0076] From these Figs. 8 to 10, comparing the cold rolled steel sheet before a galvanized treatment in which the parent phase is a microstructure of ferrite-pearlite with the cold rolled steel sheet before a galvanized treatment in which the parent phase is a microstructure of tempered martensite or tempered bainite, it is understood that the latter microstructure is better than the former microstructure to improve relatively good balanced properties between a tensile strength (TS) and a total elongation (E1) and a hole enlarging rate (λ) by selection of preferred alloy heating treatment temperature and time (as shown in Figs. 8 and 9).

[0077] Also in the retained γ property of the microstructure, comparing the former material with the latter material, it is understood that the former material can get a better property than that of the latter material by selection of a preferred alloy heat treating temperature.

Claims

1. A high tensile strength steel sheet excellent in processibility which comprises a matrix and a second phase, the matrix comprising at least tempered martensite or tempered bainite and, if necessary, ferrite as a constituent, and the second phase comprising retained austenite as a constituent, wherein

   (1) the steel comprises C: 0.10 to 0.6 mass%, Si: 1.0 mass% or smaller, Mn: 1.0 to 3 mass%, Al: 0.3 to 2.0 mass%, P: 0.02 mass% or smaller, S: 0.03 mass% or smaller,
   (2) a volume rate of retained austenite obtained by a saturated magnetization measuring method is 5 to 40% by area (whole field is 100%), and
   (3) a relationship of a carbon amount (C: mass%) in the steel, a volume rate (fγR) of retained austenite and a carbon concentration (CγR) of the retained austenite satisfies the following equation (I):

$$(f\gamma R \times C\gamma R) / C \geq 50 \qquad \text{(I)}$$

2. The high tensile strength steel sheet according to claim 1 or 2, wherein the steel further contains at least one selected from the group consisting of Ca: 0.003 mass% or smaller, and REM: 0.003 mass% or smaller.

3. The high tensile strength steel sheet according to claim 1, wherein the steel further contains at least one selected from the group consisting of Nb: 0.1 mass% or smaller, Ti: 0.1 mass% or smaller, and V: 0.1 mass% or smaller.

4. The high tensile strength steel sheet according to any preceding claim, wherein the steel further contains at least one selected from the group consisting of Mo: 2 mass% or smaller, Ni: 1 mass% or smaller, Cu: 1 mass% or smaller, and Cr: 2 mass% or smaller.

5. The high tensile strength steel sheet according to any preceding claim, wherein the matrix of steel comprises tempered martensite, tempered bainite and ferrite and area rates (an area of a whole photograph is 100%) of tempered martensite, tempered bainite and ferrite are, when measured with an optical microscope photograph, as follows:

   Tempered martensite or tempered bainite: 20 to 90% by area
   Ferrite: 0 to 60% by area

6. The high tensile strength steel sheet according to any preceding claim, wherein the retained austenite contains lath-like retained austenite having a long axis/short axis ratio of 3 or larger at 60% by area relative to total retained austenite.

7. The high tensile strength steel sheet according to any preceding claim, which has a surface which is processed by galvanizing.

8. The high tensile strength steel sheet according to claim 7, wherein-the galvanizing process is a melting-galvanizing.

9. The high tensile strength steel sheet according to claim 7 or 8, wherein after the galvanizing process the steel sheet is further subjected to heat treatment for alloying.

10. The high tensile strength steel sheet according to any preceding claim, wherein the steel sheet is provided with a tensile strength (TS) of 750 to 1050MPa and a condition where a tensile strength (TS), a total elongation (E1) and a hole enlarging rate (λ) satisfy a relationship of the following equation:

$$TS \times E1 \geq 22{,}000, \; TS \times \lambda \geq 20{,}000$$

[wherein TS represents result of measurement of a tensile strength (unit: MPa), E1 represents result of measurement of a total elongation (unit: %), and λ represents result of measurement of a hole enlarging rate (unit: %)].

11. A method of preparing a high tensile strength steel sheet excellent in processibility which comprises steps of: providing a steel sheet comprising C: 0.10 to 0.6 mass%, Si: 1.0 mass% or smaller (including 0% by mass), Mn: 1.0 to 3 mass%, Al: 0.3 to 2.0 mass%, P: 0.02 mass% or smaller, and S: 0.03 mass% or smaller, with a martensite or bainite introduced therein, cold rolling the steel sheet at rolling reduction rate of 30% or smaller or without performing cold rolling, thereafter heating the steel sheet to a ferrite-austenite 2-phase region temperature, and then retaining the steel sheet in a temperature range of 450 to 550°C for 10 to 500 seconds.

12. The method of preparing a high tensile strength steel sheet according to claim 11, which further comprises steps of subjecting the steel sheet to a galvanizing process and if necessary an alloy heating process.

13. The method of preparing a high tensile strength steel sheet according to claim 11, which further comprises steps of subjecting the steel sheet to a galvanizing process and if necessary an alloy heating process from the 2-phase region temperature heating time and/or the austemper time of 450 to 550°C to get a galvanized steel sheet.

Fig. 1

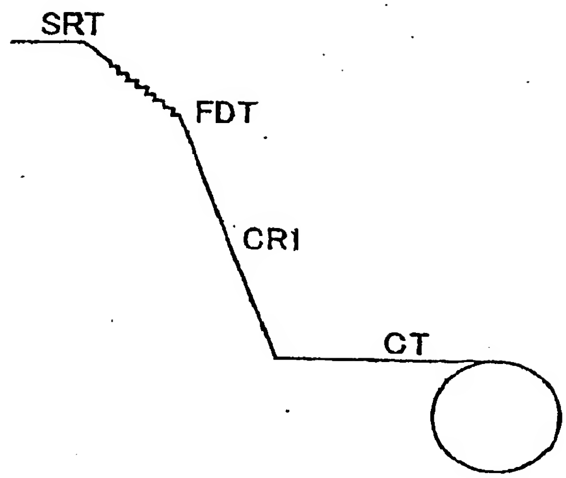


Fig. 2

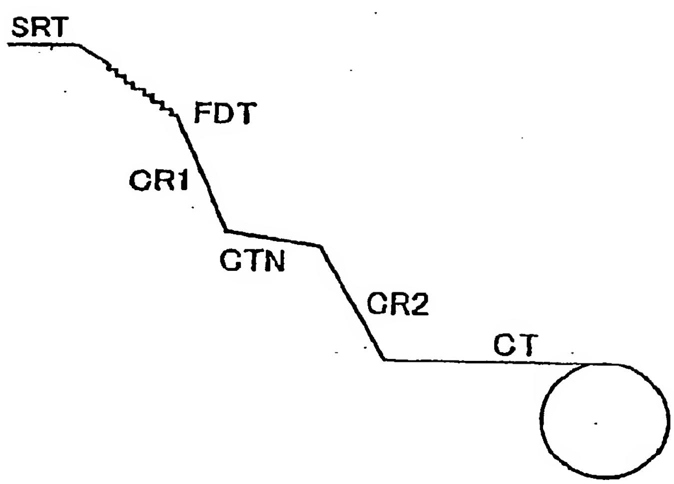


Fig. 3

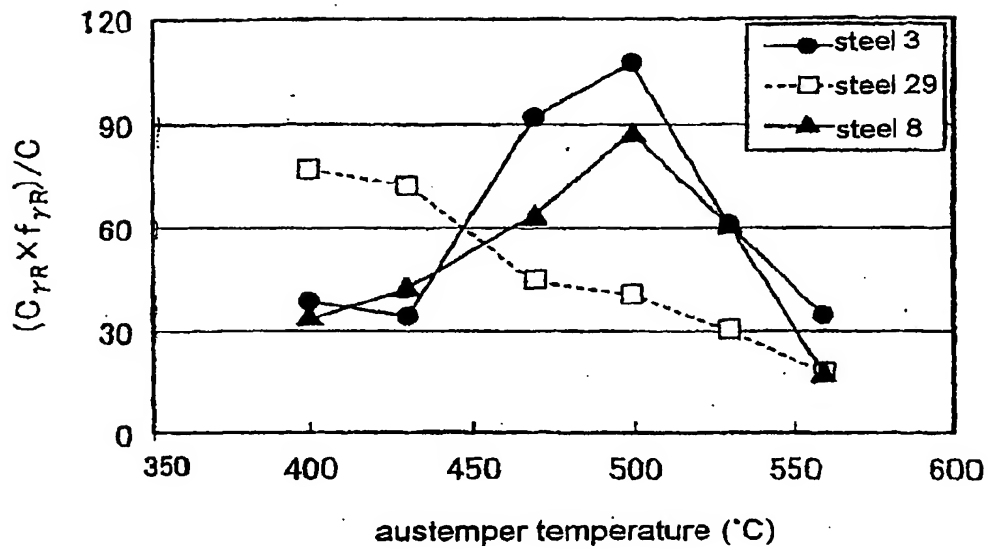

120
90
60
30
0
350
400
450
500
550
600
steel 3
steel 29
steel 8
$(C_{\gamma R} \times f_{\gamma R})/C$
austemper temperature (°C)

Fig. 4

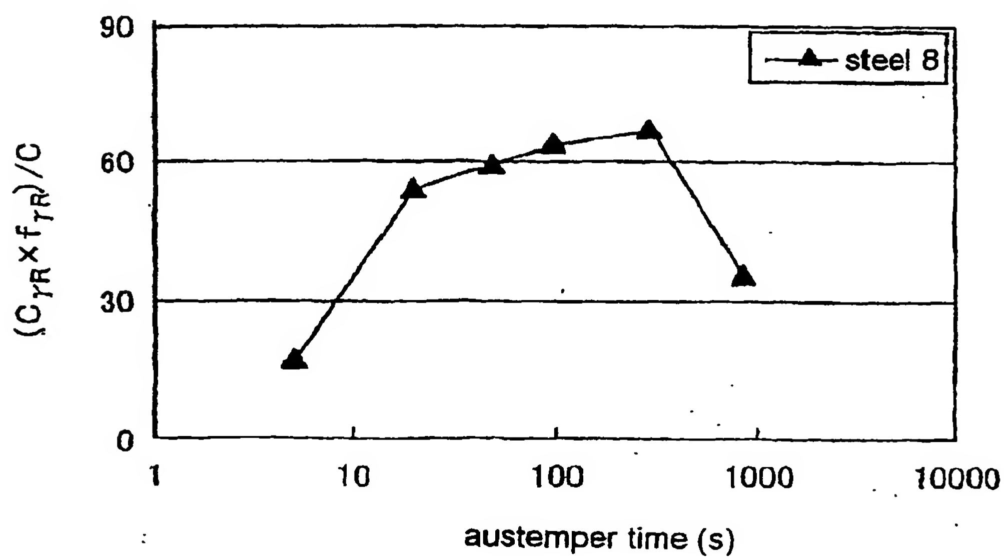

90
60
30
0
1
10
100
1000
10000
steel 8
$(C_{\gamma R} \times f_{\gamma R})/C$
austemper time (s)

Fig.5

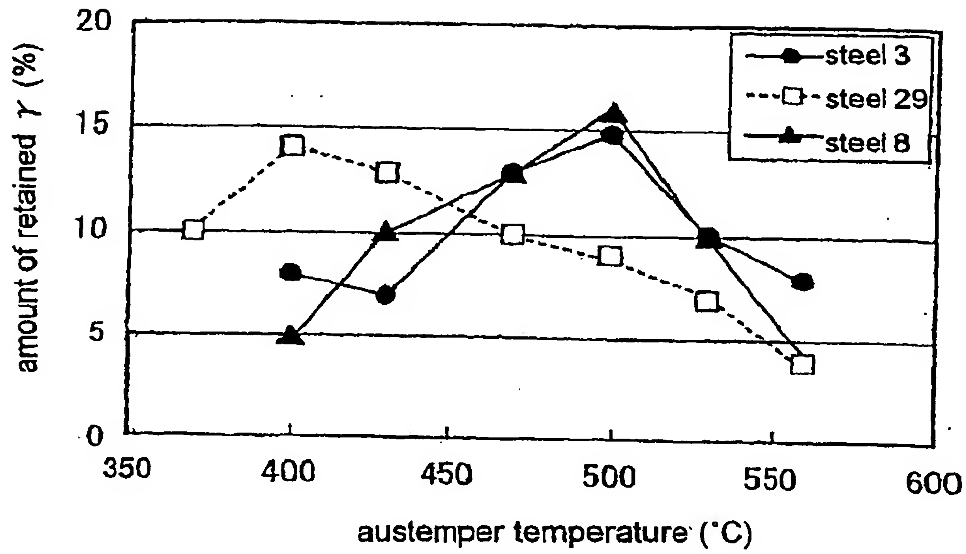

20
15
10
5
0
350
400
450
500
550
600
amount of retained γ (%)
austemper temperature (°C)
steel 3
steel 29
steel 8

Fig. 6

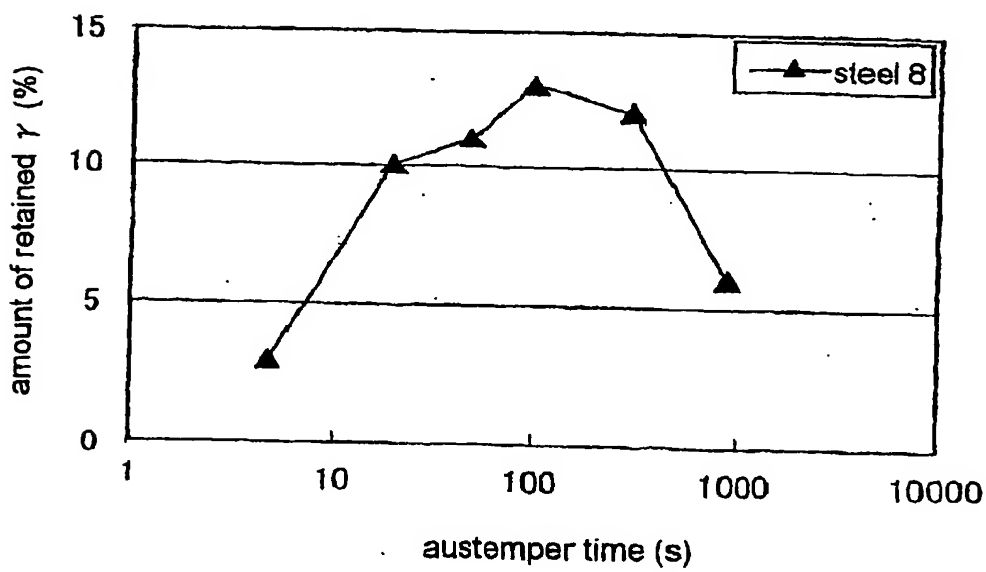

15
10
5
0
1
10
100
1000
10000
amount of retained γ (%)
austemper time (s)
steel 8

Fig. 7

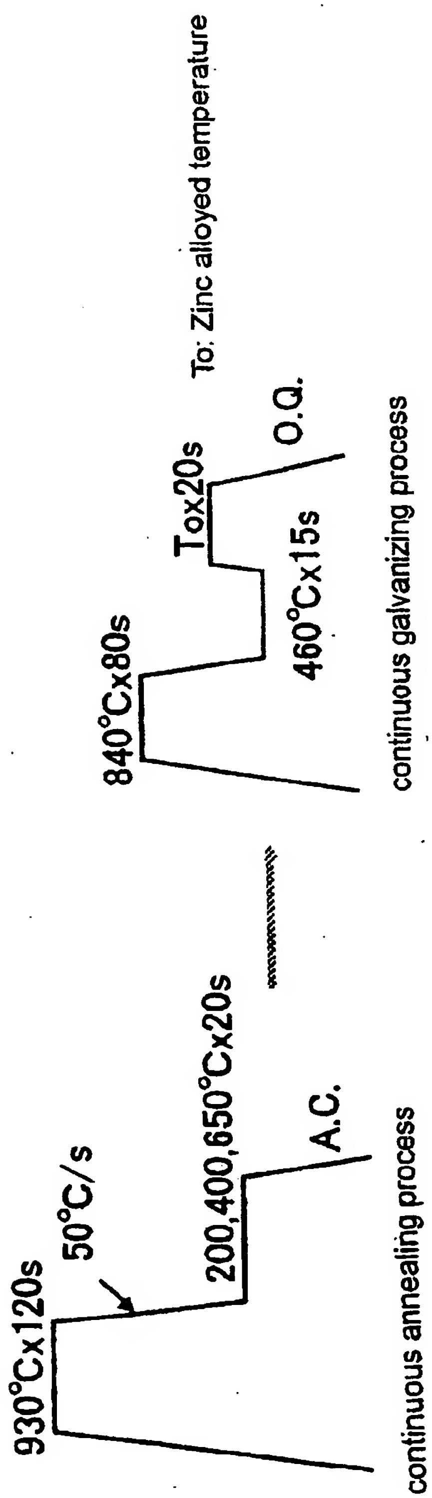

930°Cx120s
50°C/s
200,400,650°Cx20s
A.C.
continuous annealing process
840°Cx80s
460°Cx15s
Tox20s
O.Q.
To: Zinc alloyed temperature
continuous galvanizing process

Fig. 8

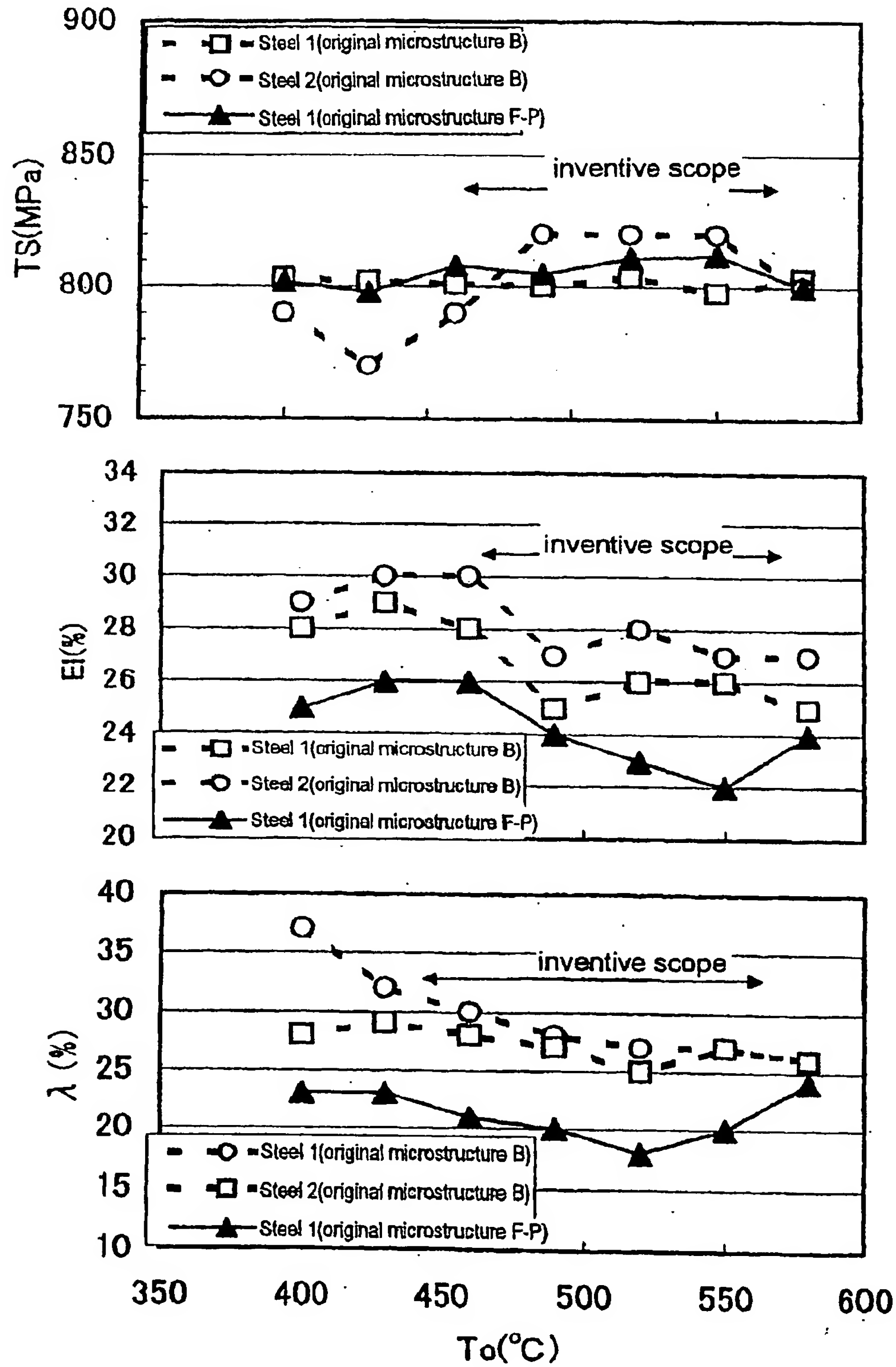

900
850
800
750
TS(MPa)
Steel 1(original microstructure B)
Steel 2(original microstructure B)
Steel 1(original microstructure F-P)
inventive scope
34
32
30
28
26
24
22
20
El(%)
inventive scope
Steel 1(original microstructure B)
Steel 2(original microstructure B)
Steel 1(original microstructure F-P)
40
35
30
25
20
15
10
λ (%)
inventive scope
Steel 1(original microstructure B)
Steel 2(original microstructure B)
Steel 1(original microstructure F-P)
350
400
450
500
550
600
To(°C)

Fig. 9

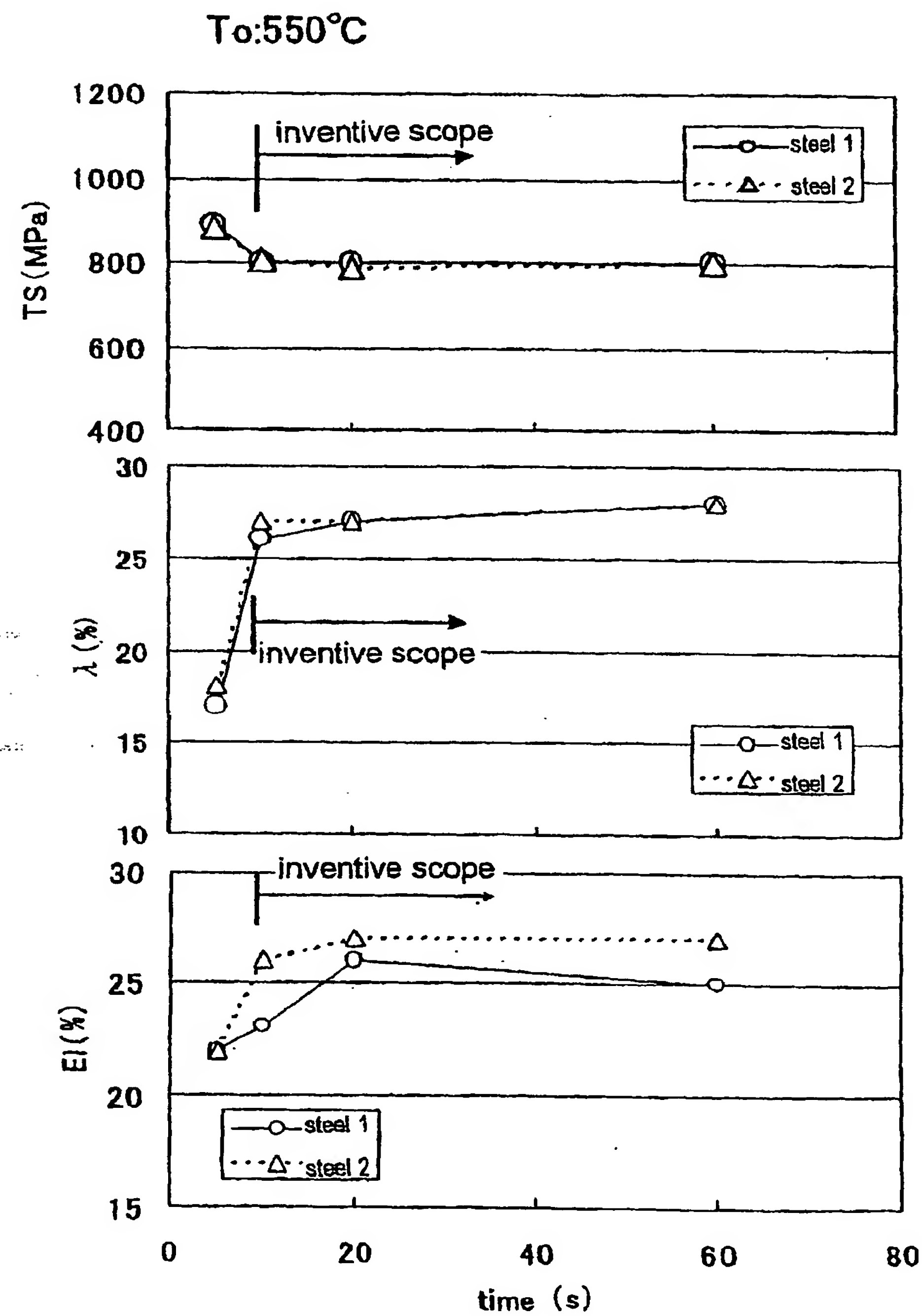
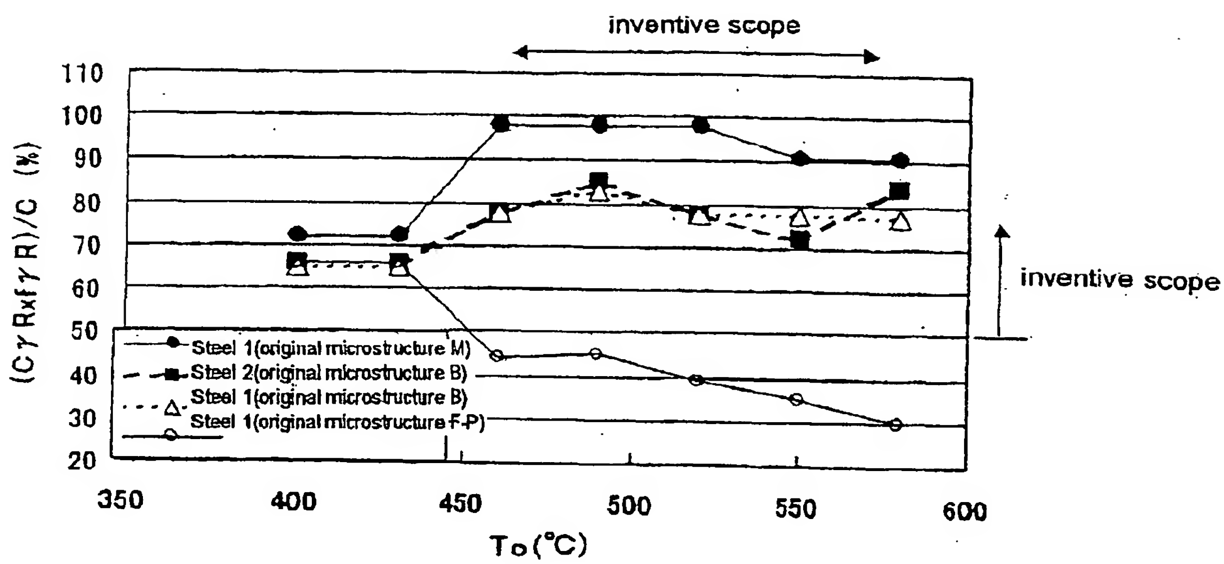

To:550°C
1200
1000
800
600
400
TS (MPa)
inventive scope
steel 1
steel 2
30
25
20
15
10
λ (%)
inventive scope
steel 1
steel 2
30
25
20
15
El (%)
inventive scope
steel 1
steel 2
0
20
40
60
80
time (s)

Fig. 10



inventive scope
110
100
90
80
70
60
50
40
30
20
(Cγ Rxfγ R)/C (%)
Steel 1(original microstructure M)
Steel 2(original microstructure B)
Steel 1(original microstructure B)
Steel 1(original microstructure F-P)
inventive scope
350
400
450
500
550
600
To(°C)

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(54) High tensile strength steel sheet excellent in processibility and process for manufacturing the same

(57) A high tensile strength steel sheet excellent in processibility which can satisfy a strength, a total elongation, and stretch-flanging property (hole enlarging rate) at a further high level. and comprises a matrix microstructure of tempered martensite or tempered bainite and, if necessary, ferrite, and a second phase of retained austenite, wherein (1) the steel comprising C: 0.10 to 0,6 mass%, Si: 1:0 mass% or smaller, Mn: 1.0 to 3 ,mass%, Al: 0.3 to 2.0 mass%, P: 0.02 mass% or smaller, S: 0.03 mass% or smaller, (2) a volume rate of retained austenite obtained by a saturated magnetization measuring method is 5 to 40% by area (whole field is 100%), and (3) a relationship of a carbon amount (C: weight%) in the steel, a volume rate ($f\gamma R$) of retained austenite and a carbon concentration ($C\gamma R$) of the retained austenite satisfies the equation:

$$(f\gamma R \times C\gamma R) / C \geq 50 \qquad (I)$$

EP 1 512 760 A3

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EUROPEAN SEARCH REPORT

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